NORSAR

ROYAL NORWEGIAN COUNCIL FOR SCIENTIFIC AND INDUSTRIAL RESEARCH

Scientific Report No. 2-77/78

SEMIANNUAL TECHNICAL SUMMARY

1 October 1977 - 30 April 1978

Edited by

H. Gjøystdal

Kjeller, May 1978

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I. SUMMARY

This report describes the operation and research activities at the Norwegian Seismic Array (NORSAR) for the period from 1 October 1977 to 31 March 1978.

The performance of the NORSAR Detection Processor has been somewhat improved relative to the previous reporting period (uptime increased from 88.8% to 91.6%), although the Special Processing System (SPS) has caused a considerable number of breaks, the longest one lasting for nearly 5 days. The regular operation of the new Event Processor (AUTOEP) was resumed as of 1 October 1977, and the results are now published in a NORSAR Monthly Bulletin which is distributed to about 60 recipients. Statistics from the first half year of operation show an average of 12.3 reported events per day, which is 63% of the number reported prior to the array reduction The operation of the data center is working fairly well with one manned shift. The maintenance contract with IBM was reduced by 1 October 1977, and the NORSAR personnel have thereby increased their engagement in problems tied to malfunctioning of the IBM equipment (tape drives, SPS, etc.). The performance of the data communications systems (including the ARPA network) can be characterized as good, although the number of outages increased during the last 3 months of the period. The Detection Processor has not been subject to major changes, however, the AUTOEP system has been significantly improved in order to meet the various user requirements. The performance of the array instrumentation has been stable and satisfactory, and the main channel characteristics show very little change from previous periods.

The research activities are described in 11 separate subsections of the last chapter of this report and cover research conducted under NTNF's contract with ARPA as well as research projects sponsored by Norwegian authorities. The first subsection is on the work of the seismological expert group established by the Conference of the Committee on Disarmament (the CCD) of the United Nations. The second one deals with statistical

models for seismic magnitude, and the following two are on P-wave amplitude anomalies and inversion of travel time data. Then follow two contributions presenting results from the new microearthquake array in Svalbard, one deals with microearthquake surveillance and one with the teleseismic detectability of the array. The next subsection describes a maximum likelihood method for epicenter location based on S-P time differences. Then follow one report on precisely located earthquakes in the vicinity of the NORSAR array, and one on macroseismic data collection using newspaper ads. The next one deals with the seismicity of East Africa, and the last subsection discusses lithosphere thickness in the general NORSAR siting area.

H. Gjøystdal

II. OPERATION OF ALL SYSTEMS

II.1 Detection Processor (DP) Operation

There have been 111 breaks in the otherwise continuous operation of the DP system in this reporting interval. The uptime percentage is 91.6%, as compared to 88.8% for the last reporting period (April-September 1977). Fig. II.1.1 and the accompanying Table II.1.1 both show the daily DP downtime for the days between 1 October 1977 and 30 March 1978. The monthly recording times and up percentages are given in Table II.1.2. As can be seen from Table II.1.1 the dominant component governing the DP system performance is the SPS. Of the 111 breaks in this period, 70 were caused by this unit alone. Also, three of these breaks lasted for more than two continuous days, with the longest, 117 hours, break from 24 February to 1 March. The breaks can be grouped in the following categories:

a)	SPS malfunctioning	70
b)	Maintenance stops	9
c)	Error on the Multiplexor Channel	8
d)	Stops related to system operation	8
e)	Hardware problems	5
f)	Power jumps and breaks	4
g)	Stops related to program changes or tests	4
h)	Stops related to possible program errors	2
i)	Magnetic tape drive problems	1

Apart from Category a), the numbers in the other categories are relatively normal. The high number of maintenance stops (9) is partly related to a CPU error on the 360-A machine, but also reflects the extra effort from NORSAR personnel doing preventive maintenance on the SPS unit.

The total downtime for this period was 363 hours 10 minutes. The mean-time-between-failures was 1.5 days, which is the same as for the earlier reporting period (April-September 1977).

D. Rieber-Mohn

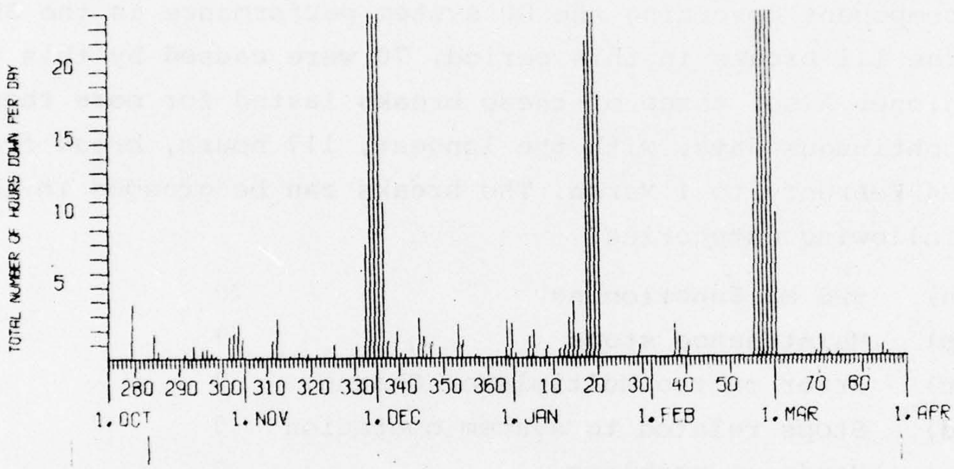

Fig. II.1.1 Online System Downtime, October 1977-March 1978.

LIST OF BREAKS IN DP PROCESSING THE LAST HALF-YEAR

DAY	START		STOP		COMMENTS..........
279	8	37	12	26	SPS MAINTENANCE
284	13	17	13	42	PROGRAM CHANGE
284	13	50	15	8	PROGRAM CHANGE
285	10	25	10	54	PROGRAM CHANGE
287	8	20	8	28	MPX/LATE ERROR
291	10	55	11	11	POWER JUMP
293	14	58	15	51	TAPE DRIVE
295	18	34	19	8	SPS ROS WORD ERROR
296	12	1	12	33	SPS ROS WORD ERROR
296	13	4	13	10	SPS ROS WORD ERROR
297	14	20	14	44	MAINTENANCE
298	8	6	8	13	MAINTENANCE
301	1	15	2	2	SPS ROS WORD ERROR
301	2	9	2	27	SPS ROS WORD ERROR
301	8	32	8	40	SPS ROS WORD ERROR
301	9	14	9	32	SPS ROS WORD ERROR
302	14	20	16	2	SPS ROS WORD ERROR
303	6	3	8	22	SPS ROS WORD ERROR
304	2	2	3	6	SPS ROS WORD ERROR
304	7	47	8	1	EOC MAINTENANCE
305	8	25	8	29	EOC MALFUNCTION
307	15	4	15	10	NO HDR CHECK
308	8	25	8	31	MAINTENANCE
311	12	9	12	28	POWER BREAK
311	16	13	17	3	SPS FAILURE
312	3	4	4	3	SPS FAILURE
312	4	26	4	55	SPS FAILURE
312	5	34	6	52	SPS FAILURE
315	14	42	14	50	ARAPANET PROBLEMS
317	2	30	2	54	SPS FAILURE
[illegible]	8	22	8	39	2821 MAINTENANCE
321	8	33	8	47	PROGRAM CHANGE
325	6	34	9	12	HARDWARE ERROR (A)
325	13	39	13	59	ONLINE BACK TO A
330	10	6	10	53	SPS FAILURE
332	16	6	24	0	SPS FAILURE
333	0	0	24	0	SPS FAILURE
334	0	0	24	0	SPS FAILURE
335	0	0	24	0	SPS FAILURE
336	0	0	10	54	SPS FAILURE
337	7	26	8	36	SPS FAILURE
339	8	36	9	51	SPS FAILURE
339	23	26	24	0	HARDWARE ERROR (A)

TABLE II.1.1

(Sheet 1 of 3)

LIST OF BREAKS IN DP PROCESSING THE LAST HALF-YEAR

DAY	START		STOP		COMMENTS...........
340	0	0	0	1	HARDWARE ERROR (A)
340	8	3	8	9	SPS FAILURE
340	10	45	10	57	CPU ERROR
340	11	55	12	0	SPS FAILURE
341	13	53	14	7	SPS FAILURE
344	20	43	22	57	POWER FAILURE & SPS
344	23	5	23	38	SPS FAILURE
345	0	22	0	52	CPU ERROR
345	6	16	7	20	SPS FAILURE
346	7	32	7	45	2701 (B) TURNED OFF
347	20	45	21	52	SPS FAILURE
349	16	37	17	21	SPS FAILURE
353	18	42	21	1	POWER FAILURE & SPS
354	7	45	8	1	B TURNED ON
354	8	24	9	0	MAINTENANCE
354	17	20	17	42	MPX/LATE ERROR
357	9	52	10	4	SPS FAILURE
364	2	54	3	23	SPS FAILURE
364	11	1	11	9	SPS FAILURE
364	11	39	12	4	SPS FAILURE
364	12	21	13	35	SPS FAILURE
365	4	24	5	18	SPS FAILURE
365	14	50	16	23	SPS FAILURE
365	23	58	24	0	CHANGE OF YEAR
1	0	0	0	21	CHANGE OF YEAR
4	18	56	19	29	POSSIBLE PROG ERROR
4	19	58	20	5	1052 HANGUP
4	21	54	22	40	SPS FAILURE
5	0	37	2	28	SPS FAILURE
5	10	22	10	27	SPS FAILURE
8	6	17	7	10	SPS FAILURE
11	6	19	6	56	SPS FAILURE
12	21	59	22	42	SPS FAILURE
12	23	50	24	0	SPS FAILURE
13	0	0	0	28	SPS FAILURE
13	1	25	2	2	SPS FAILURE
13	6	54	7	28	SPS FAILURE
13	10	11	10	16	SPS FAILURE
13	13	23	13	31	SPS FAILURE
13	21	19	22	6	SPS FAILURE
13	22	17	22	24	MPX/LATE ERROR
14	1	38	2	21	SPS FAILURE
14	7	23	8	0	SPS FAILURE
14	9	53	11	25	SPS FAILURE

TABLE II.1.1

(Sheet 2 of 3)

LIST OF BREAKS IN DP PROCESSING THE LAST HALF-YEAR

DAY	START		STOP		COMMENTS..........
14	12	5	12	17	SPS FAILURE
14	13	16	13	26	SPS FAILURE
14	16	6	16	17	SPS FAILURE
14	20	20	20	53	SPS FAILURE
15	17	55	18	34	SPS FAILURE
15	19	30	20	2	SPS FAILURE
15	22	30	22	58	SPS FAILURE
16	8	50	9	2	MPX/LATE ERROR
17	1	58	24	0	SPS FAILURE
18	0	0	24	0	SPS FAILURE
19	0	0	24	0	SPS FAILURE
20	0	0	18	14	SPS FAILURE
25	14	19	14	24	SPS FAILURE
27	12	13	12	17	DATE CORRECTION
29	15	[illegible]	16	50	SPS FAILURE
32	8	12	8	17	LAST START INVALID
37	9	0	10	3	SPS FAILURE
37	12	18	12	43	2311 MAINTENANCE
37	14	39	14	45	2311 MAINTENANCE
37	21	34	22	15	SPS FAILURE
38	0	45	1	29	SPS FAILURE
38	20	9	20	49	SPS FAILURE
40	15	[illegible]	15	49	SPS FAILURE
40	15	54	16	13	SPS FAILURE
55	12	21	24	0	SPS FAILURE
56	0	0	24	0	SPS FAILURE
57	0	0	24	0	SPS FAILURE
58	0	0	24	0	SPS FAILURE
59	0	0	24	0	SPS FAILURE
60	0	0	9	50	SPS FAILURE
60	13	49	13	58	SPS FAILURE
69	6	28	6	46	MPX/LATE
70	11	42	13	12	SPS FAILURE
72	6	7	8	19	MPX/LATE
74	7	2	7	16	MPX/LATE
81	4	55	6	8	SPS FAILURE
84	11	49	12	36	SPS FAILURE
85	11	42	11	58	SPS FAILURE
89	8	41	8	46	MPX/LATE

TABLE II.1.1

(Sheet 3 of 3)

Month	DP Uptime (Hrs)	DP Uptime (%)	No. of DP Breaks	No. of Days with Breaks	DP MTBF* (Days)
Oct	728.1	97.9	20	14	1.4
Nov	657.1	91.3	16	14	1.7
Dec	690.2	92.8	26	16	1.1
Jan	640.0	86.0	30	17	0.9
Feb	559.9	83.3	10	9	2.3
Mar	729.4	98.0	9	9	3.4
Total Period	4004.8	91.6	111	79	1.5

* MEAN-TIME-BETWEEN-FAILURES = (Total uptime/No. of Up Intervals).

TABLE II.1.2

Online System Performance

October 1977 - March 1978

II.2 Event Processor Operation

The regular operation of the Event Processor, using the AUTOEP, was resumed as of 1 October 1977. The results are now published in a NORSAR Monthly Bulletin, usually issued within two weeks after the last data date, and distributed to about 60 recipients.

Some statistics from the first 6 months of operation are given in Table II.2.1, where it is seen that 12.3 events have been reported every day in average. This is 63% of the number of events reported during the same 6 months in 1975/76, a drop which mainly reflects the reduction of the array from 22 to 7 subarrays. When more data are available, we will look more closely at this drop in detectability, as well as the location accuracy, and compare with expected results.

P. Engebretsen

H. Bungum

Table II.2.1

	Teleseismic	Core	Sum	Daily
Oct 77	215	165	380	12.3
Nov 77	162	52	214	7.1
Dec 77	303	32	335	10.8
Jan 78	156	54	210	6.8
Feb 78	149	114	263	9.4
Mar 78	798	57	855	27.6

II.3 NORSAR Data Processing Center (NDPC) Operation

Data Center

The operation of the data center is still working fairly well with just one manned shift, although routine jobs cover more than 1/4 of the shift. The users have, however, learned to operate the computer so that they can run their jobs outside the manned shift, if necessary.

The DP uptime for the period is 91.6% and although it is better than the last half year, the number of stops and breakdowns of the SPS have increased. There have been three major breakdowns on the SPS and those breakdowns stand for 6.8% of the downtime, the other SPS stops 1% and other reasons 0.6%. The number of stops outside office hours caused by the SPS is 47. This is an increment of more than 50% compared to the last half year.

Since the maintenance contract with IBM was reduced (by nearly 50%) 1 October 1977, NORSAR personnel have solved most problems in connection with tape units. Also the EOC equipment has been taken care of. In most problems with the IBM 360/40 (B) and the SPS the same personnel have been involved, and to a certain degree reduced the IBM engagement.

J. Torstveit
O.A. Hansen

Data Communications (National)

The first 3 months were characterized by relatively few outages, both with respect to group as well as single circuits. In the last quarter the number of outages increased for both categories. Simultaneous outages for groups of circuits will almost always be caused by carrier frequency equipment. Approximately 60 outages were observed in the reporting period, of which March alone had around 40. Just a few outages of this kind exceed 1 hour in duration. The large majority are observed over one or two 16-minute intervals.

Single subarray communications circuits have also been affected by the usual reasons such as: cable damages, intermittent equalizer/amplifier operation, level fluctuations, etc.

Subarrays particularly affected:

02B	week	12,	5.0%
02C	"	2,	10.9%
04C	"	2,	6.6%
04C	"	7,	24.2%
04C	"	13,	20.0%.

In addition the above-mentioned and the remaining subarrays have been subject to outages several times, but the figures are lower and may vary between 1 and 3%.

Modems and related equipment are still in good condition. Just a few times it has been necessary to replace defective cards (separation filters). New equalizers/amplifiers were planned by NTA to be installed in November 1977. Due to delays in delivery the equipment is still not installed.

Table II.4.1 shows outages/degraded performance with respect to subarray communications circuits.

II.4 The ARPA Subnetwork (TIP to TIP, i.e., TIP incl. modems, lines and interfaces)

The London Communications Circuit

Apart from line level adjustment (10/24) and loss of carrier (11/09), reliable performance. The Norwegian Telegraph Administration (NTA)/Oslo got Network Control Center (NCC) permission to break the communications path in connection with replacement of an equalizer.

The SDAC Communications Circuit

11/09 Loss of carrier approx. one hour.

12/05 NCC suspected line trouble, as SDAC claimed discontinuity in data transfer between the two data centers. A modem test was run to eliminate possible malfunction in that device.

12/09 Trouble with the system most of the day from 0700 GMT. Otherwise, fair operation.

The Terminal Interface Message Processor (TIP)

TIP preventive maintenance (PM) carried out in accordance with Bolt, Beranek and Newman (BBN) schedule. With a few exceptions the system has been running continuously during most of the period. A Very Distant Host (VDH) test was implemented by Mr. Kelley of BBN 10 November 1977. The system was taken down for about two hours.

We have also experienced teletype trouble a few times. 5 January communication with NCC was impossible, as NCC had great difficulties in reading us. Messages addressed to NORSAR, however, were easily interpreted. The interface card (in the CPU) was the possible cause for the trouble. The teletype was partly inoperative in February. A card was replaced (02/25).

TIP Connections

No change in the connection of the IMP part of the TIP since last report. On the other hand, a few changes have been made with respect to TIP port (LIU) connections. Eleven ports are occupied, of which the Norwegian Defence Research Establishment (NDRE) occupies 6 (Nos. 2, 4, 12, 40, 41 and 42), NORSAR 2 (Nos. 3 and 6), Norwegian Telegraph Administration/Research Establishment 1 (No. 54), University of Oslo 1 (No. 50), Regneanlegget Blindern-Kjeller (RBK) 1 (No. 1).

O.A. Hansen

Sub-Array	Oct (4) (3-30.10)		Nov (4) (31.10-27.11)		Dec (4) (5.12-1.1)		Jan (3) (2-15.1/23-29.1)		Feb (4) (30.1-26.2)		Mar (4) (6.3-2.4)		Avg. ½ year	
	>20	>200	>20	>200	>20	>200	>20	>200	>20	>200	>20	>200	>20	>200
01A	0.2	0.7	0.9	0.7	1.2	0.2	0.6	0.6	1.3	3.8	5.1	3.5	1.6	1.6
01B	0.2	0.2	1.0	1.5	0.9	0.2	1.5	0.6	1.6	3.2	3.4	1.6	1.4	1.2
02B	1.4	3.5	1.0	1.2	0.6	0.2	0.6	0.6	2.3	1.3	9.2	2.1	2.5	1.5
02C	1.0	0.9	5.8	2.2	4.9	5.2	1.5	12.7	2.7	4.3	6.1	4.8	3.7	5.0
03C	0.5	0.7	1.4	0.7	0.9	1.1	0.6	0.6	1.3	1.8	5.7	1.0	1.7	1.0
04C	0.7	1.4	2.3	1.6	0.6	0.2	7.2	2.3	1.7	26.4	5.2	23.9	3.0	9.3
06C	---	1.3	1.5	0.5	0.4	0.2	0.2	1.2	1.8	0.8	4.7	1.9	1.4	1.0
AVG	0.6	1.2	2.0	1.2	1.4	1.1	1.7	2.7	1.8	5.9	5.6	5.5	2.2	2.9
Less								02C 1.0		04C 2.5		04C 2.5		04C 1.3

Table II.4.1

Communications (degraded performance >20/outages >200). Figures in per cent of total time. Month, 4 weeks as indicated (January 3, March 4, due to SPS outage).

III. IMPROVEMENTS AND MODIFICATIONS

III.1 Detection Processor

The modifications to this system have been minor within this reporting period. The system seems to be relatively bug-free, and the two errors corrected (see below) were not critical for the performance.

- As was discovered at SDAC, the subfield identifications were not correct in the result record from the Online Event Processor, transmitted over the ARPANET. This was caused by a programming error in the PNRSAD module, and was promptly corrected 12 November.

- The Alternate Telemetry Command (ATC) code 08 (Channel Gain Measurement), initiated from the EOC, gave incorrect results. This was traced back to a missing input card for the Core Image Tape Generation program. A re-run of this program, with the missing card added, produced a new Core Image tape. The invalid ATC code 08 (and other related commands) gave proper results after system restart with the new Core Image tape, on 17 November.

III.2 Event Processor

The new AUTOEP processing system, which reads Online Event Processor (OEP) results off the Detection Log Tape and performs further processing on these data, has been improved, in order to meet user requirements. The program may now be stopped gracefully at any time, giving back the results achieved up to this point. Also, the program can be told to defer processing until OEP results later than a certain time have been read in from the Detection Log tape. Thus the analyst may stop the program at will and restart from the same point later. A remaining problem is that improper/invalid data infrequently causes a program check in the filtering routine. Code for checking traces before filtering, and for trapping program checks, will, however, shortly be implemented.

A version of this program, using the concurrent plotting feature, is also available. When this version is running, event plots will be generated at the same time as an event is processed. In cases where results from a sequence of events are wanted as soon as possible, this feature should come in handy.

Since manual repunching of a large proportion of the produced bulletin cards from this program seems necessary, work to build an extension to this system has started. All bulletin lines produced by the AUTOEP program are now automatically written to a Disk Bulletin File (DBF) at the end of processing. A new program will access the DBF and display bulletin lines upon the screen of the 2260 Display Station. Lines may then be modified by the analyst. An important new feature in this program will be the automatic recomputation of parameters which are related to parameters changed by the analyst (i.e., change in arrival time gives automatic change in the origin time). A final 'publish' will produce copies of the edited bulletin lines on cards or tape.

D. Rieber-Mohn

III.3 Array Instrumentation and Facilities

A leftover modification from 1976, namely, modification of BE-lightning protection cards (Larsen et al, 1975) was completed at 04C in October 1977.

As of 7 November the standard low pass filters with upper 3 dB point at 4.75 Hz were replaced by filters with upper 3 dB points at 8.0 Hz on channels 01A06, 02B06, 02C06, 04C06 and 06C06. The frequency response is not measured exclusively for these channels, for practical use the frequency response of NORSAR Analog SP Station, ref. Fig. III.3.1 can be consulted.

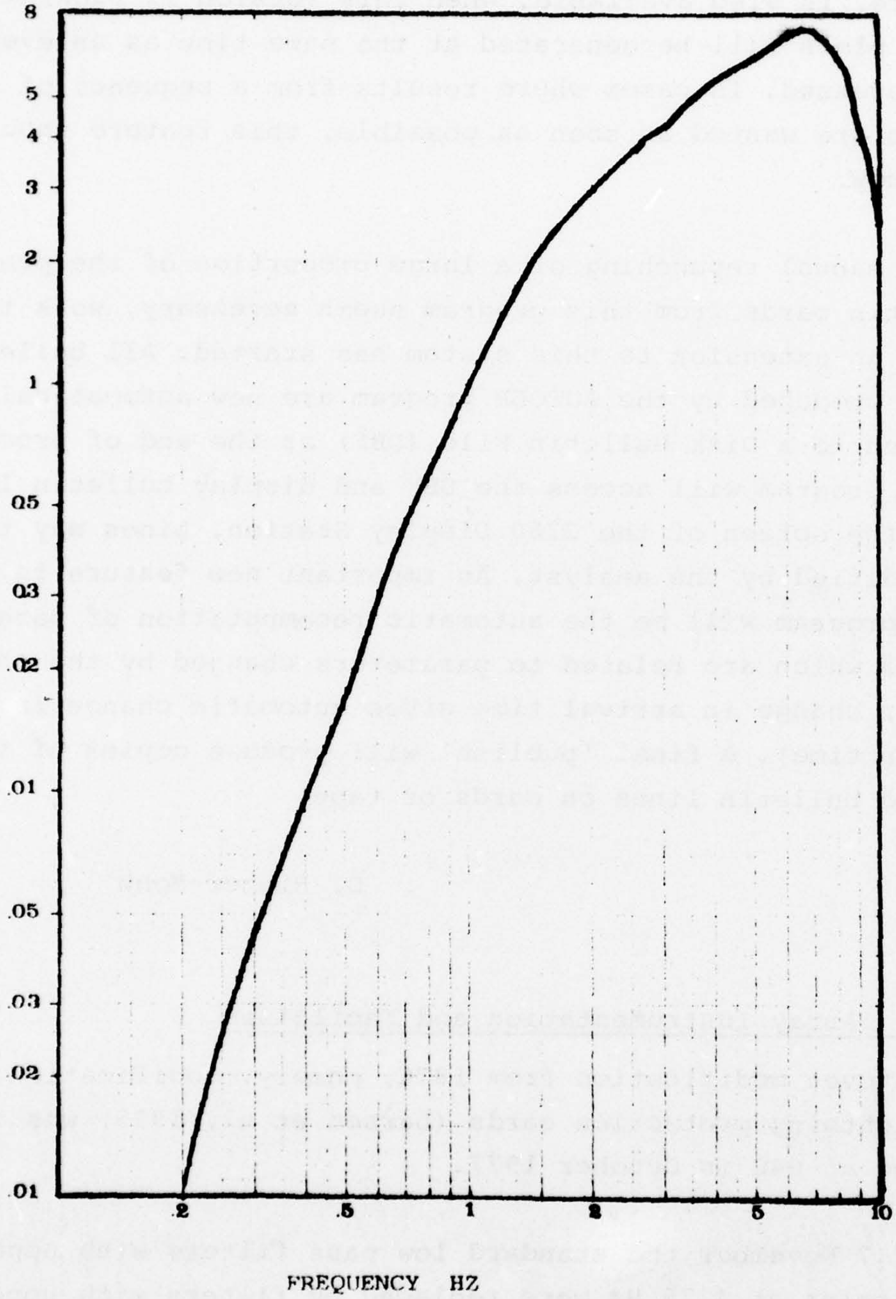

Fig. III.3.1 Magnification of ground motion relative to magnification at 1.0 Hz of NORSAR Analog SP Station, March 1977.

From 15 March a Teledyne Geotech S-500 seismometer has been in operation at 06C channel 02, up to 30 March in vertical position and thereafter in NS horizontal position. The connections are given in Fig. III.3.2. An internal report will be issued when the test period is completed.

A. Kr. Nilsen

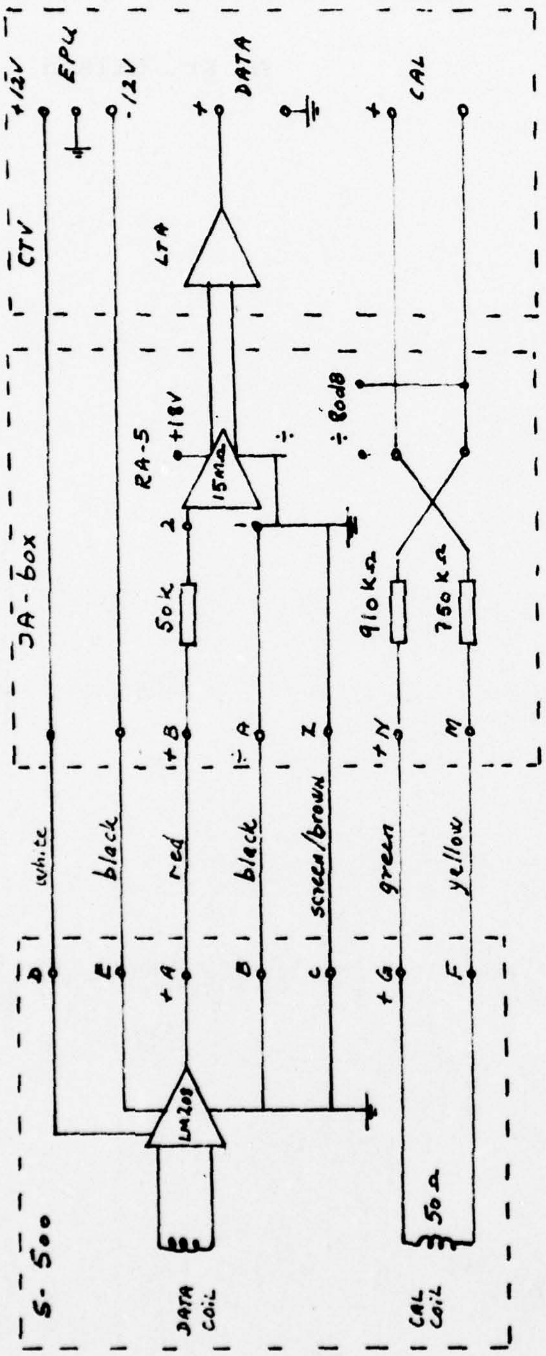

Fig. III.3.2 Geotech S-500 seismometer connections at 06C02, March 1978.

IV. MAINTENANCE ACTIVITY

A brief review of the maintenance accomplished at the subarrays by the field technicians as a result of the remote array monitoring and routine inspections is given. The monitoring schedule has not been changed in the period.

Maintenance Visits

Fig. IV.1 shows the number of visits to the subarrays in the period. The subarrays have on the average been visited 6.7 times (without 01A, 4.5 times). The large number of visits to 01A are due to cable breakages, dryout and painting of the LPV and LP tanks and complete checkout of the LP seismometers. Also at 03C the LPV and LP tanks were dried out and painted.

There has been one maintenance visit on the communications system in the period.

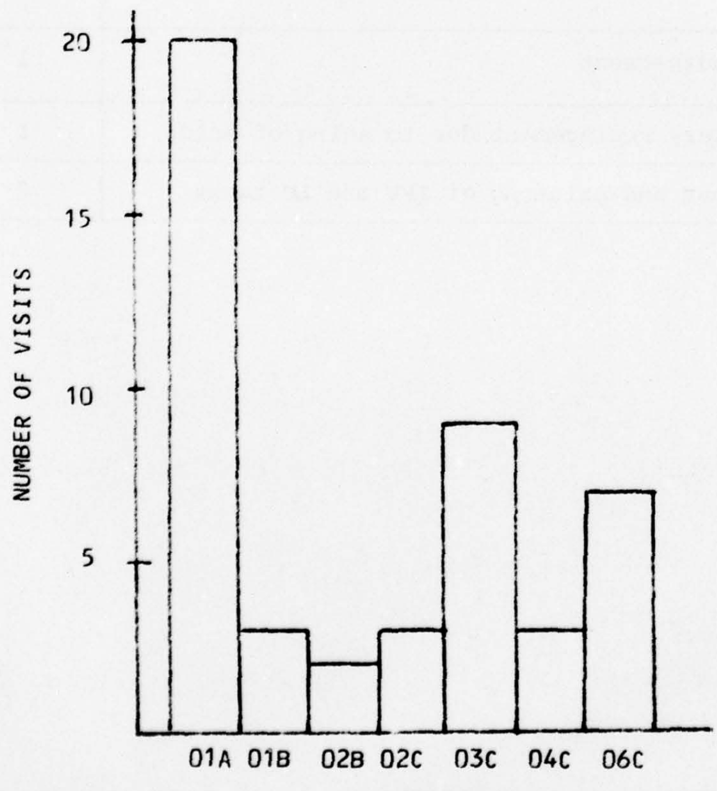

Fig. IV.1 Number of visits to the NORSAR subarrays in the period 1 October 1977 to 31 March 1978.

Preventive Maintenance Projects

The preventive maintenance work in the array is described in Table IV.1. The adjustments are corrections of characteristics within the tolerance limits.

Table IV.1

Preventive Maintenance Work in the Period

1 October 1977 to 31 March 1978

Unit	Action		No. of Actions
LTA	Adjustment of DC offset	SP	11
		LP	0
	Adjustment of channel gain	SP	5
		LP	3
Seis-mometer	MP adjustment (in field)		3
SLEM	BB adjustment		1
Power	Battery replacement due to aging of acid		1
Facilities	Dryout and painting of LPV and LP tanks		2

Disclosed Malfunctions on Instrumentation and Electronics

Table IV.2 gives the number of accomplished adjustments and replacements of field equipment in the array with the exception of those mentioned in Table IV.1.

Table IV.2

Total number of required adjustments and replacements in the NORSAR data channels and SLEM electronics (1 Oct 1977 - 31 Mar 1978)

Unit	Characteristic	SP Repl.	SP Adj.	LP Repl.	LP Adj.
Seism-mometer	Damping				2
	RCD			10	
	Magnets			1	
	MP (field)				2
	FP (field)				2
Seism. Ampl. RA-5	Cal. amp. circ.	1			
	Balance		2		
	Gain		1		
LTA	DCO		1		1
	Ch. Gain		2		1
	CMR		6		
SLEM BB Gen.			1		
1 Hz Gen			1		
EPU		2	1		

Malfunction of Rectifiers, Power Loss, Cable Breakages

There has been no malfunction of the rectifiers in the period. The number of cable breakages was two, requiring 6 days' work by the field technicians.

Array Status

Average values of some of the characteristics are given in Tables IV.3 and IV.4, compared with nominal values.

Table IV. 3

Average values of the channel resolution and channel voltage as of 31 March 1978

Subarray	Channel Resolution			
	SP		LP	
	PM/QU	Voltage P-P	NM/QU	Voltage P-P
01A	42.14	5.79	2.48	4.92
01B	41.27	5.91	2.54	4.80
02B	41.80	5.84	2.61	4.67
02C	40.94	5.96	2.61	4.88
03C	40.80	5.98	2.53	4.82
04C	42.10	5.80	2.56	4.77
06C	45.52	5.36	2.60	4.69

Table IV.4

Average array channel characteristics values as of 31 March 1978

Chan.	Channel Resolution				DC Offset		Nat. Freq.		Damping	
	PM/QU	Nominal	Volts P-P	Nominal	Millivolts	Nominal	Hz	Nominal		Nominal
SP	42.09	42.7	5.80	5.71	-0.2	0	1.03	1.00	0.69	0.70
LP	NM/QU 2.54	2.47	4.80	4.94		0	-	20.0	0.648	0.64

Conclusion

Also in this period the array instrumentation performance has been stable and satisfactory. As can be seen under the section of array status the main channel characteristics are close to nominal and with little change from previous periods.

Alf Kr. Nilsen

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ABBREVIATIONS

BB	-	Broad band
CAL	-	Calibration
CMR	-	Common mode rejection
CTV	-	Central Terminal Vault
DC	-	Direct current
DCO	-	DC offset
EPU	-	External power unit
FP	-	Free period
LP	-	Long period
LPV	-	Long period vault
LTA	-	Line Termination Amplifier
MP	-	Mass position
NM	-	Nanometer
PM	-	Picometer
P-P	-	Peak-to-peak
QU	-	Quantum units
RA-5	-	SP seismograph amplifier
RCD	-	Remote centering device
SLEM	-	Seismic short and long period electronics module
SP	-	Short period

V. DOCUMENTATION DEVELOPED

V.1 Reports, Papers

Christoffersson, A., 1978: Statistical models for seismic magnitude, NORSAR Scientific Report 1-77/78, March 78.

Gjøystdal, H., 1977: Final Technical Summary, NORSAR Scientific Rep. No. 3-76/77, Nov. 77.

Haddon, R.A.W., and E.S. Husebye, 1978: Joint interpretation of P-wave time and amplitude anomalies in terms of lithospheric heterogeneities, Geophys. J.R. Astr. Soc., in press.

Husebye, E.S., P.C. England and I.B. Ramberg, 1978: The ideal-body concept in interpretation of the Oslo Rift gravity data and their correlation with seismic observations, In: I.B. Ramberg and E. Neumann (eds.): The Oslo Paleo-rift, NATO ASI Proceedings,

Rieber-Mohn, D., 1978: The use of ARPANET for transmission of real time seismic data, NORSAR Internal Rep. No. 1-77/78, NTNF/NORSAR, Kjeller, Norway.

Rieber-Mohn, D., 1978: Documentation of the NCP task, NORSAR Internal Rep. No. 2-77/78, NTNF/NORSAR, Kjeller, Norway.

Sacks, I.S., A. Snoke and E.S. Husebye, 1978: Lithospheric thickness beneath the Baltic Shield, Tectonophysics, in press.

Tjøstheim, D., 1978: Autoregressive modelling and spectral analysis of array data in the plane, Geophys., in press.

Tjøstheim, D., and O.A. Sandvin, 1978: Multivariate autoregressive feature extraction and the recognition of multichannel waveforms, IEEE Trans. on Comp., in press.

L.B. Tronrud

V.2 Program Documentation

Two documents have been completed during this period, describing how plotting can be performed concurrently with the plot-generating program.

N/PD-91 describes the new foreground plotting program FDPLOT, which cooperates with the background program and receives plot data from it, via a shared disk file, before passing these to the plotter.

N/PD-92 describes the modified PLOT subroutine, that writes the plot data to the shared disk file, and communicates with the foreground [illegible]PLOT program, using the interpartition signalling facility in the operating system.

D. Rieber-Mohn

VI. SUMMARY OF SPECIAL TECHNICAL REPORTS/PAPERS PREPARED

In this section a brief summary is given of the results of ongoing and recently completed research projects at NTNF/NORSAR. The presentation covers research conducted under NTNF/NORSAR's contract with ARPA as well as research projects sponsored by Norwegian authorities. Of particular interest to the seismic discrimination problem among the Norwegian-funded undertakings is the participation of two NTNF/NORSAR seismologists in the seismological expert group established by the United Nations. In addition, some of the research conducted at NTNF/NORSAR in connection with seismic risk studies is also of general seismological interest, and is therefore included in the following.

VI.1 Work of the Seismological Expert Group Established by the United Nations

On 22 July 1976 the Conference of the Committee on Disarmament (the CCD) of the United Nations established an Ad Hoc group of Government-appointed experts to consider and report on international cooperative measures to detect and identify seismic events, so as to facilitate the monitoring of a comprehensive test ban. Representatives of a total of 27 nations participated in the expert group, which met in Geneva, Switzerland, in five sessions. Its final report was transmitted to the CCD on 9 March 1978 and contained specific recommendations for a global system. In short, the main elements of the recommended system were:

- (i) A systematic improvement of the observations reported from a network of more than fifty seismological observatories around the globe.
- (ii) An international exchange of these data over the Global Telecommunications System of the World Meteorological Organization.
- (iii) Processing of the data at special international data centers for the use of the participant states.

The report also considered some steps, such as an experimental exercise, which could be taken initially to assist the establishment of such a cooperative data exchange system.

The Norwegian government appointed Dr. E.S. Husebye and Dr. F. Ringdal, both of NTNF/NORSAR, to represent Norway in the expert group. Dr. Ringdal was chosen by the group to act as its scientific secretary. While the participation in the expert group was funded by Norwegian authorities, part of the research work done at NTNF/NORSAR in this connection has also been of relevance to the NTNF/NORSAR's ARPA contract. For example, a comprehensive detectability study of nearly 500 globally distributed seismograph stations was undertaken, and the results have now been published (Ringdal et al, 1977).

For supplementary comments on the work of the <u>Ad Hoc</u> group, we refer to the editorial of <u>Nature</u>, 6 April 1978 (see Fig. VI.1.1), where political and scientific implications of the proposed measures are discussed.

E.S. Husebye

F. Ringdal

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nature 6 April 1978

Twenty years of test ban talk

IN 1958, a conference of scientific experts in Geneva made the first steps towards devising an international seismic monitoring system which would verify compliance with any treaty banning underground nuclear weapons' tests. In 1968, with political interest in a comprehensive test ban in the doldrums but with ten years of seismological research on a national basis completed, SIPRI, the Stockholm International Peace Research Institute, convened further informal meetings of scientists in an attempt to get a comprehensive test ban (CTB) talked about again. Now in 1978, with serious political discussion proceeding both at superpower level and amongst a wide range of nations at the UN Conference of the Committee on Disarmament (CCD), scientists have again reported on what must be done in an international context to monitor a test ban treaty. Their report, the result of deliberations by scientists from 27 countries over a period of a year and a half, has recently been released (as CCD document 558). It reflects substantial credit on its participant, especially on Dr Ulf Ericsson from Sweden, its chairman, and Dr F. Ringdal from Norway, its scientific secretary, for although there was a clear need to hammer out some form of consensus in the document, this has not prevented its message from being clear and unambiguous.

The science of test-ban monitoring was mostly done in the 1960s. Techniques to increase detectability, to discriminate between explosions and earthquakes, to relate seismic magnitude to explosive yield, to locate events more accurately were all developed rapidly during that period, and have in recent years undergone relatively little further change. What has happened in the past ten years, however, has been a marked improvement in data handling. Studies which used to take months of data accumulation and hand measurement can now be done in a morning at a computer console. Many international communication links, both formal and informal, now exist and more are planned. This, of course, is true in many other branches of science and greatly benefits research, but in seismology the bonus is that it is now possible to talk of an international centre or centres, with rapid access to data of a high quality from seismometers all round the world, providing a routine flow of information highly relevant to the verification of a CTB. In many ways the recent report is a blueprint for such an operation, which might be preceded by an experiment taking up to two years.

It is of interest to compare the predictions of network capability which are being made in 1978 with those put forward in 1968 (which came essentially from a pre-digital era). The detection of events almost invariably depends on the successful registration above noise levels of so-called body waves. This detection capability has improved roughly threefold; explosions of yields of 1 or 2 kilotons in hard rock in most parts of the Northern Hemisphere would now most likely be picked up. The improvement in detection of surface waves, necessary to the identification of explosions as such, is even greater. Identification might now be possible for shots as low as 5 to 10 kilotons in hard rock.

Not all the progress, however, is in the science and technology. For the past twenty years the Soviet Union's willingness to co-operate in a scheme of test-ban monitoring has been in doubt. Many times she has declared that she is perfectly prepared to sign a treaty, but that she regards 'national means' as adequate for verification. Since the Soviet national seismic network is of very limited value in monitoring the United States, this statement is open to the interpretation that the nature of US society is such that clandestine small-yield testing would be impossible. But the corollary is that the nature of Soviet society, and even the geography, leaves the door open to violation and that much wider open if the Soviet Union will provide no data to international agencies. It is too little realised that at present even the informal channels by which seismologists exchange data are closed on the days that the Soviet Union conducts an underground test.

The recent discussions, however, offer some promise. The Soviet Union, a rather hesitant participant to begin with, eventually co-operated fully, and even allowed five of its own stations to be used in various calculations —in contrast to the French and Chinese who stayed away. The next step will be when data from these five stations are supplied on a routine basis. This is unlikely to happen before a treaty is signed—the Soviet Union would regard provision of such material, containing possible evidence of weapons tests, as tantamount to handing out state secrets. But if the long-term intention is to participate fully, this must be regarded as an optimistic sign.

A comprehensive test ban needs much more than a good verification network to bring it into being. But this report is bound to provide some reassurance, particularly in the United States, that such a network, including Soviet stations, is possible. The proposals will not guarantee that tests at the kiloton level can be positively identified as such. But they do show some evidence—for the first time—of truly international goodwill. □

Fig. VI.1.1

VI.2 Statistical Models for Seismic Magnitude

The concept of seismic magnitude - a measure of the kinetic energy of the elastic waves released by an earthquake -- was first suggested by C.F. Richter in 1936 (see Richter, 1958). Magnitude measurements, which give an indication of the relative size of earthquakes, are today routinely made at all seismological observatories and represent an integral part of many research investigations. In the context of seismic event classification, i.e., discrimination between earthquakes and underground nuclear explosions, the magnitude parameter is of paramount importance. The reason is simply that despite extensive research efforts the so-called m_b:M_s discriminant is still considered the most reliable one and is also the most widely used. On the other hand, in certain branches of seismology like source mechanism studies the parameter seismic moment has replaced magnitude (to a large extent) for indicating the size of large earthquakes (e.g., see Kanamori and Anderson, 1975). In other parts of seismology the magnitude parameter has been somewhat discredited because of its considerable variability due to different physical factors, some of which are difficult or impossible to quantify. It must, however, be said that some of the research aimed at the magnitude problem must be rated as rather primitive.

In view of the importance of the magnitude parameter in a seismic discrimination context, NORSAR scientists have in recent years given a considerable attention to the magnitude problem. The study has been focused on:

(i) whether parts of the observed magnitude scattering was associated with inhomogeneities in the earth (forward scattering of small-scale inhomogeneities),

(ii) the magnitude estimation itself, and finally

(iii) developing discriminants having a better performance than that of the m_b:M

This section, together with section VI.3, describes some recent efforts regarding the first two factors mentioned above, namely, the scattering of the P-wave amplitude observations and in particular the proper estimation of m_b-magnitudes given the observations from a network of seismograph stations and arrays. Extensive studies show that the P-wave amplitude variations across the NORSAR array are rather large and may be clearly associated with structural heterogeneities at the bottom of the lithosphere (see Sec. VI.3). This amplitude scattering has a relatively short wavelength, i.e., varying rapidly with small changes in distance and azimuth. Also, the amplitude distribution across the NORSAR array may be approximated by a lognormal statistical distribution. This behavior has also been observed for worldwide amplitude data, and implies that the station magnitude correction term and thus the scattering term in magnitude estimation models can be considered a Gaussian variable. A novel approach to the magnitude estimation problem was the work of Ringdal (1976), who introduced a maximum likelihood technique for estimating magnitude from a network of stations, thereby taking into account information on stations being operational, but not detecting weaker events. Ignoring the latter kind of information would in most cases result in a positive magnitude bias for small events.

The mentioned maximum likelihood approach has recently been further elaborated by Christoffersson (1978). His approach differs from that of Ringdal (1976) in that it takes into account the probability that the event is actually detected by the network, whereas Ringdal (1976) considered, in statistical terms, a sample space which also included cases where an event was not seen by any of the stations in the network. The practical difference in the estimates provided by the two methods is generally small, and the relative merit of the two approaches will not be discussed here.

In summary, the statistical models presented in the paper by Christoffersson (1978) in connection with seismic magnitude deals with two main situations. The first concerns the estimation of magnitude for an event using a fixed network of stations and taking into account the detection and bias properties of the individual stations. The second treats the problem of estimating seismicity and detection and bias properties of individual stations. The models are applied to analyze the magnitude bias effects for an earthquake aftershock sequence from Japan, as recorded by a hypothetical network of 15 stations. It is found that network magnitudes computed by the conventional averaging technique are considerably biased, and that a maximum likelihood approach using instantaneous noise level estimates for non-detecting stations gives the most consistent magnitude estimates. Finally, the models are applied to evaluate the detection characteristics and associated seismicity as recorded by three VELA arrays (UBO, TFO, WMO).

While the two statistical situations discussed by Christoffersson (1978) each provide powerful techniques for eliminating the bias caused by non-detections of individual stations of a network, they are in general suited for two different estimation problems. The first (or <u>conditional</u>) approach is useful mainly for estimating the magnitude of individual events, and can be applied equally well to earthquakes and explosions. The second (or <u>unconditional</u>) approach, gives a convenient framework for joint estimation of structural parameters such as seismicity (a and b in the recurrence formula $\log N = a - b \cdot M$) and station bias. It can also be used to estimate station detection characteristics. This second method is a unified approach which provides a generalization of earlier works of Kelly and Lacoss (1969) and Ringdal (1975).

Perspectives. The various maximum likelihood approaches discussed above for ensuring consistent magnitude estimates have to our knowledge only been applied to m_b-observations. The main reason for this is that this kind of magnitude data are the only ones which are easily and abundantly available. There is no reason why these novel estimation techniques should not be applicable/extended to surface wave magnitude (M_s) estimation, and also other significant problems in a discrimination context like the $m_b:M_s$ relationship in particular for weak events. Research on these types of problems is now in progress, and our efforts here are concentrated on one hand on developing algorithms where, for example, possible correlation between the P and Rayleigh wave detectability for a given station is taken into account, and on the other hand to constructing comprehensive $m_b:M_s$ data bases from both array and SRO-recordings. The use of advanced statistical techniques in analyzing the $m_b:M_s$ relationship is expected to give more definite answers to a number of questions as to the nature of the relationship; e.g., the range over which it may be considered linear, the associated slope (both for explosion and earthquake populations) and most importantly, its behavior at low magnitudes where the problems due to non-detections are considered to be most significant.

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VI.3 Short Period P-wave Amplitude Variability

In an earlier NORSAR technical summary report (Gjøystdal, 1977) we described in some detail a rather extensive experiment on a deterministic approach to the analysis of short period P-wave amplitude anomalies as observed across the NORSAR array. The essence of this work was that from observed travel time residuals various models for lithospheric velocity contrasts in the form of thin lenses were constructed. Then using a finite difference calculation scheme the expected P-wave amplitude distribution was obtained which in turn was compared to that actually observed from real events. The best fit between observed and calculated amplitude anomalies was obtained for lenses in the depth range 150-200 km, although the theoretical amplitude values could only account for about some 40% of the variance in the observational data. However, the fit between observed and theoretical results is clearly better than the quoted number indicates, that is, the respective anomaly patterns are quite similar and the indicated deteriorated fit stems partly from problems in 'exact' positioning of the two patterns. A reasonable physical explanation here appears to be that the observed wavelength of observed P-time anomalies is significantly larger than that of corresponding P-amplitude anomalies which implies that the 'time'-derived lens models are not sufficiently detailed for very precise amplitude calculation. A consequence of this hypothesis is that the reverse process should be more rewarding, that is, we would intuitively expect a better fit if we tried to predict time anomalies. This has actually be achieved using an energy flux formulation for the lens focusing/defocusing effects which ultimately led to a Poisson differential equation. The main results here were a correlation of about 0.90 between observed and predicted time anomalies.

On the basis of this study (Haddon and Husebye, 1978) it is concluded that time and amplitude anomalies originate from the same lithospheric structures which, as a good first approximation,

may be represented in terms of a 2-D heterogeneous layer at depths around 150-200 km or the bottom of the lithosphere. We note in passing that the lithosphere, an integral concept of modern plate tectonics, is not well defined seismologically. However, more recent observations, also at NORSAR, of S-to-P converted waves indicated a well-defined discontinuity at a depth of around 230 km (Sacks et al, 1978; see also Sec. VI.11) which may be taken to indicate a lithospheric thickness of the same order. Furthermore, velocity perturbations required for accounting for the anomalous P-wave amplitude observations amounts to a few per cent and thus are directly compatible with similar results obtained by Aki et al (1976, 1977) and by scattering analysis of precursor and coda waves (Husebye et al, 1976; King et al, 1975; Haddon et al, 1977).

Perspectives. The above study has been completed (Haddon and Husebye, 1978) and some wider applications have been considered, that is, can the methodology used here be adapted to other arrays, networks or conventional seismograph stations. Indeed, we have undertaken some preliminary analysis of LASA data but as the spatial earthquake sampling of this array is less symmetrical than that of NORSAR we have temporarily halted this work. As pointed out above, a major problem in reproducing amplitude anomalies from time anomalies is the difference in wavelengths of these two types of anomalies. On the other hand, the time residual projection scheme used in constructing the lens models has proved very valuable in analysis of absolute travel time anomalies (say those listed in ISC-catalogues). For example, using absolute NORSAR time anomalies we have reproduced those areas of overlap of the thin lens models derived from relative travel times. This result was not too unexpected in view of the exceptionally high quality of the NORSAR data, but as demonstrated by Husebye and Ringdal (1978), the above projection scheme may also be an alternative to conventional analysis of time residuals from seismograph networks of continental dimensions. Furthermore, we are also considering a joint inversion scheme of NORSAR time

and amplitude data and in this particular case based on ray tracing principles. Finally, we do consider this type of problem, that is, a better understanding of intrinsic amplitude variations in particular for near-field observations in the distance range $0^{\circ}-30^{\circ}$ to be of fundamental importance in a seismic discrimination context. A key word to success here is of course flexibility in modelling seismic heterogeneities in the mantle.

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R.A.W. Haddon (Univ. of Sydney)

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VI.4 Inversion of Travel Time Data

The NORSAR interest in geophysical inversion problems dates back to the summer of 1974 when Professor K. Aki, MIT, visited Kjeller. The research then initiated resulted in development of a novel and in particular flexible technique for inversion of travel time residuals so as to produce a 3-D image of the seismic velocity anomalies beneath the array or network in question (e.g., see Aki, Christoffersson and Husebye (ACH), 1976, 1977, and Husebye et al, 1976). This particular inversion technique has become rather popular for detailed studies of lithospheric heterogeneities in various parts of the U.S. and also Japan and even adapted to inversion of time residuals from the global seismographic network (Dziewonski et al, 1977).

In the amplitude inversion experiment described in Sec. VI.3 we mentioned that the construction of the thin lenses used in calculating theoretical amplitude values was based on a relatively simple projection scheme which resulted in a 2-D seismic velocity anomaly model. Furthermore, Haddon and Husebye (1978) used essentially the same data as Aki et al (1977) (see VI.3) so apparently the two mentioned studies gave conflicting results and/or the bulk of lithospheric inhomogeneities are confined to a relatively thin layer in the lower part of the lithosphere. We do consider that the differences between the Aki et al (1977) and Haddon and Husebye (1978) studies can be partly reconciled by using more homogeneous model specifications and partly reflect a fundamental problem in seismology, namely, that of discriminating between a relatively thick, weakly inhomogeneous layer and on the other hand a relatively thin, strongly inhomogeneous layer. Furthermore, in the 3-D inversion scheme the basic model parameters like number and thicknesses of layers, average layer velocities and block sizes are not subject to estimation but are specified. For example, the ACH-inversion

scheme can easily reproduce the Haddon and Husebye lower lithospheric lenses using a 2-layer model with the second one located at depths around 150-200 km, and still have roughly the same variance reduction as obtained within the original 5-layer model used in the ACH-publication. Indeed, the difference between the ACH-results and the Haddon-Husebye lens models is relatively minor as the 3 bottom layers in the ACH-model have very similar velocity anomaly patterns which in turn are very similar to that of the lens models. Besides the possibility that the velocity anomalies in the lithosphere in the NORSAR siting area may have a significant vertical extent, the specification of the ACH basic model parameters may have some important bearing on the final results and consequently on their subsequent interpretation. Part of the problems here are intuitively obvious as the standard errors of the estimated velocity anomalies are relatively larger thus implying that the physical resolution may be less than generally assumed. This problem was indeed discussed when the ACH-paper was written, but at that time hampered by limited accessability to sufficiently large computers for running the inversion program.

In view of the apparent controversy between the ACH-results and those of Haddon and Husebye, and also the popularity of the ACH-inversion technique, we have initiated research in this problem and have so far designed a scheme by which we can simulate a large class of basic model specification parameters by only solving a limited number of the total number of linear equations involved. So far the corresponding programming efforts have been minor, but the computer programs are expected to be completed in the near future.

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VI.5 Microearthquake Surveillance of Svalbard

Up until now only very limited data have been available for the study of the seismic activity in and around Svalbard, and most of the studies so far have been based on teleseismic data (Hodgson et al, 1965; Sykes, 1965; Husebye et al, 1975; Bungum, 1977). However, even if only about 1-2 intraplate earthquakes from Svalbard are reported every year from the teleseismic recordings, the large (M_s=5.9) event in the Storfjorden area on 18 January 1976 clearly showed that a certain seismic hazard is present. The fact that this event had a faulting mechanism atypical for intraplate earthquakes (Bungum, 1977) also emphasized the need for a closer investigation, which could be done only by installing seismic stations on the archipelago itself.

A program for such microearthquake surveillance of the Svalbard Archipelago was initiated by installation of seismic stations in Barentsburg (BBG), Longyearbyen (LYR) and Pyramiden (PRD), in cooperation between the Russian mining trust 'Arktikugol', Store Norske Spitsbergen Kullkompani, the Norwegian Polar Institute and NTNF/NORSAR (Bungum et al, 1978). The installation of the seismometers (Sprengnether MEQ-800) was done in December 1977, and the operation during the first few weeks was somewhat unstable; this was due to various technical problems most of them instabilities related to installation in sub-zero temperatures. For this reason, reliable time corrections were not available for the data analyzed in this report. When analyzing the first 2½ months of data, we consequently had to use only the S-P times, from which locations were calculated using a maximum likelihood procedure which also uses all available information about the various errors involved. (For details, see Section VI.7). The adopted relation between the S-P times and epicentral distance was based upon the results of Mitchell et al, 1978.

Seismograms have been available and read from the three microearthquake stations for various time intervals between 8 December 1977 and 24 February 1978 and from KBS for December and January. A total of 687 earthquakes have been detected at one or more of the stations, 515 of which (or 75%) are local events. The best station is LYR, where an average of 7.5 local events per day (corrected for down times) have been detected. The number for PRD is 4.3 and for BBG 4.8, whereas the poorest station in this respect is the WWSSN station KBS, where only 2.0 local events per day were detected (see also Section VI.6). Magnitudes have been computed for 231 of the events, and they all fall in the range 0-3, with a peak at around magnitude 1.0.

The total number of located events is 234. About one half of the events are located using 2 stations and the other half with 3 stations. The locations of the latter ones are shown as an epicenter map in Fig. VI.5.1, where a great cluster of events at the west side of Storfjorden appears as the dominating feature. The precisions of the locations are so far not good enough for a closer delineation of this highly active earthquake zone, since the size of the cluster is not much larger than the computed uncertainty ellipse for each event.

The eastern coast of West Spitsbergen in Storfjorden thus appears to be an area of high intraplate seismic activity, since an average of 7.5 events per day with a probable origin in Storfjorden have been recorded by the instrument in Longyearbyen. The work of Mitchell et al (1979) showed most of the epicenters to be confined within a narrow E-W trending zone at 77.7^{O}N about 30 km long and suggested that the fault plane of the 18 January 1976 earthquake (M_s=5.9) in this area (Bungum, 1977) was along this seismic zone. The state of stress in the crust and delineation of active

zones of weakness where faulting may take place are valuable information for present and future industrial development on Spitsbergen. Spitsbergen is cut by major fault zones dating back to Paleozoic with no associated teleseismically recorded activity (Husebye et al, 1975). A future semi-permanent network of microearthquake stations on Spitsbergen would be capable of detecting zones that are tectonically active but have a low level of seismic activity.
A further step towards this end will be taken by installation of a new station (with digital recording) in Svea (S4 in Fig. VI.5.1) in May 1978, while we hope to be able to install two more stations at a later stage (S5 and S6 in Fig. VI.5.1).

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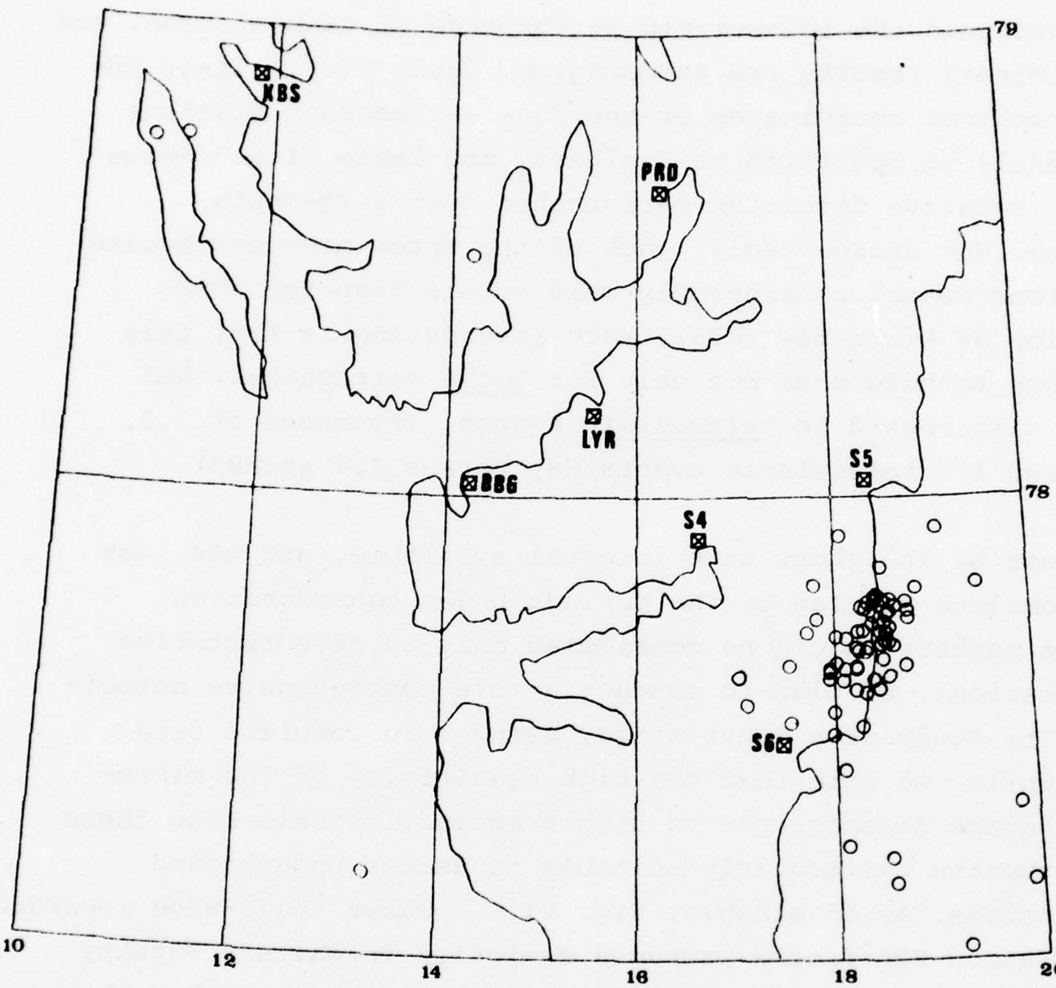

Fig. VI.5.1 Epicenter map of earthquakes located on the basis of the three stations BBG, PRD and LYR. The future station in Sveagruva is also indicated (S4), as well as two possible sites on the west side of Storfjorden (S5 and S6), that if available would greatly improve the array configuration.

VI.6 Teleseismic Detectability of the Svalbard Microearthquake Network

As discussed in Section VI.5, the primary purpose of the seismograph network installed on Svalbard north of Norway has been to survey the local seismic activity. Nonetheless, we have also investigated the teleseismic performance of each station, and preliminary results are encouraging. Table VI.6.1 lists the geographical coordinates of the four seismograph stations presently in operation on Svalbard, and Table VI.6.2 shows their relative detection performance over a 2½-month period. Not unexpectedly, each of the three microearthquake stations detect considerably more events than the WWSSN station at Kings Bay (KBS). More interesting is that this appears to hold true not only for local earthquakes, but also with regard to teleseismic events. (Averages of 2.2, 2.1 and 1.5 teleseismic events/day versus 1.4 at KBS).

Because of the short time interval available, and the lack of complete overlap of the periods under consideration, these numbers should be considered only to give tentative indications. We plan to conduct a more comprehensive detectability study at a later stage, using more complete data. Meanwhile, we note that the high sensitivity of the microearthquake seismographs to high frequency signals make these instruments particularly suitable to detect underground explosions. As an example, Fig. VI.6.1 shows the P-wave recorded at station PRD from a presumed explosion in Eastern Kazakh, 26 March 1978, with m_b(NORSAR)=5.2. Another Eastern Kazakh presumed explosion from 19 March (m_b(NORSAR)=5.1) was also detected, although the signal-to-noise ratio was considerably lower than in the former case. The epicentral distance to Eastern Kazakh is about 40 degrees; in comparison, the distance from Svalbard to Novaya Zemlya is only 10 degrees. We plan to expand the study of teleseismic and near-field detectability of the Svalbard network as more data become available.

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Table VI.6.1

Names and coordinates of the seismic stations used in this study. In the last column is given the percentage of the time between 8 December 1977 and 24 February 1978, during which each of the stations has been in operation (or data available in case of KBS).

Site	Code	Lat	Long	Data Availabilty (%)	Operated by
Barentsburg	BBG	78.073	14.240	89.5	Norwegian Polar Institute & NTNF/NORSAR
Pyramiden	PRD	78.659	16.303	58.7	
Longyearbyen	LYR	78.189	15.578	63.8	
Kings Bay	KBS	78.918	11.924	69.6	Univ. of Bergen

Table VI.6.2

Detectability statistics for the four stations used in this study. Data for the stations BBG, PRD and LYR cover the time period between 8 December 1977 and 24 February 1978, whereas data from KBS have been available only for December 1977 and January 1978. The daily averages have been corrected for station down-time.

	BBG	PRD	LYR	KBS	Total
Detected events, total	449	303	482	185	687
- Average, per day	6.3	6.5	9.6	3.4	
Detected events, local	336	199	376	111	514
- Average per day	4.8	4.3	7.5	2.0	
Detected events, teleseismic	113	104	106	74	173
- Average per day	1.5	2.2	2.1	1.4	

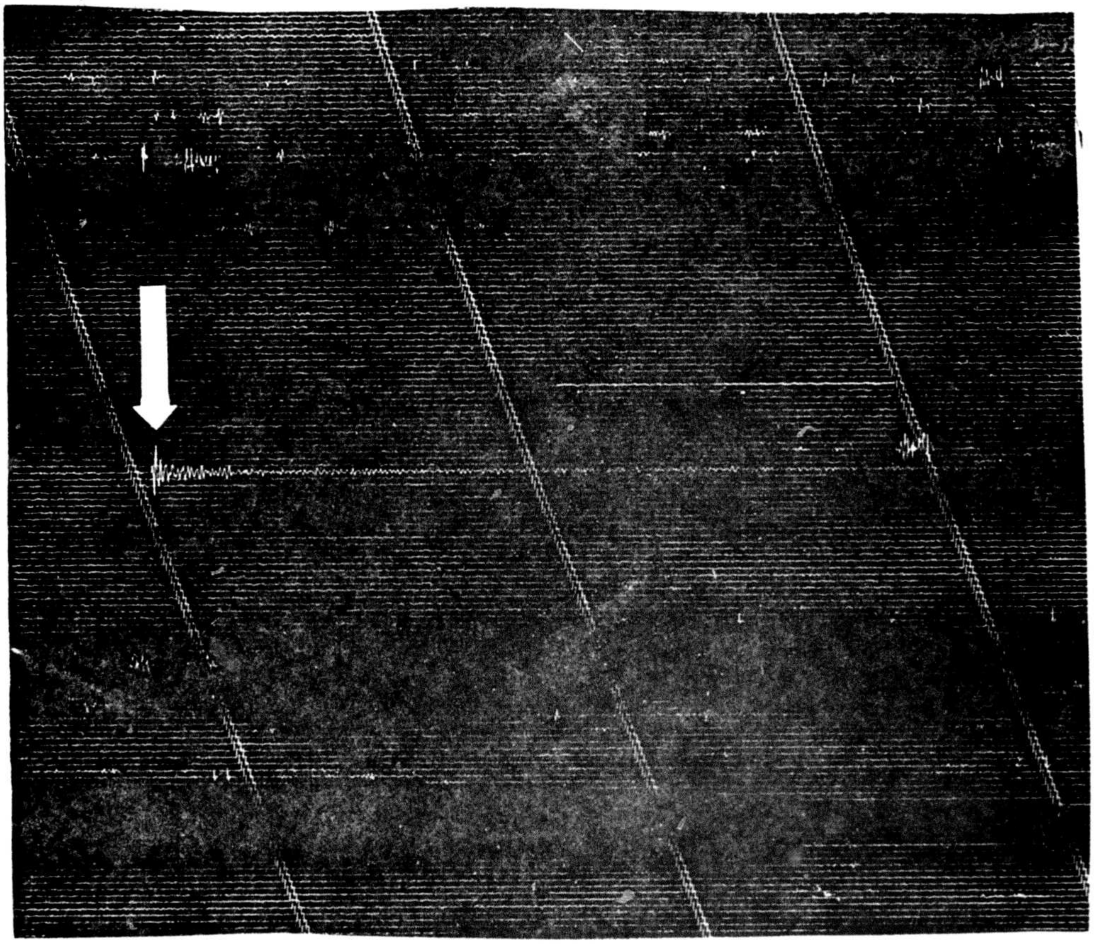

Fig. VI.6.1 P-wave recording at PRD, Svalbard, of a presumed explosion from Eastern Kazakh, 26 March 1978. Signal onset is shown by an arrow.

VI.7 A Maximum Likelihood Procedure for Local Event Location Based on Observed S-P Time Differences at Two or More Stations

A method has been developed in order to compute local event locations merely based on the relative arrival times of P and S waves observed at a number of individual stations. The method, which has been applied on data from the Svalbard microearthquake network (see section VI.5, and Bungum et al, 1978) takes advantage of the fact that there normally is a constant ratio between P and S velocities in the crust, making (for short distances) the epicentral distance Δ approximately linearly dependent upon the S-P time:

$$\Delta \simeq k \cdot t(S-P) \tag{1}$$

Knowing the epicentral distance from two stations, we may usually compute two epicenters symmetrically located about the line connecting the stations. Having a distance observation from one or more additional stations located non-symmetrically relative to the former ones, we will generally be able to choose the proper solution, however, in this case the final location should be based on a sort of 'averaging process' since the 'distance circles' will normally not intersect each other in one single point, due to the distance errors involved.

The present location procedure is based on the maximum liklihood principle from statistical theory. Assuming that the error in the 'observed' epicentral distance Δ_i for a given station i is normally distributed with zero mean and standard deviation σ_i, we may locally (close to the epicenter) approximate the 'distance circle' by a straight line and express the associated probability density function as a 'Gaussian ridge' distributed about this line (see Fig. VI.7.1):

$$p_i(x,y) = \frac{1}{\sqrt{2\pi}\,\sigma_i} e^{-\frac{1}{2}\left(\frac{a_i x + b_i y + c_i}{\sigma_i}\right)^2} \qquad (2)$$

Here, x and y are rectangular coordinates centered in a point in the vicinity of the true epicenter, and a_i, b_i and c_i are parameters defining the 'distance line' in this coordinate system.

Having chosen the origin of this system, f.ex., in the intersection point between two arbitrarily chosen distance circles, the parameters a_i, b_i and c_i may be easily computed from the station coordinates and the 'observed' value of the distance Δ_i.

When an expression like (2) has been found for N stations, we may compute the joint probability density of the epicenter by forming the product

$$p(x,y) = \prod_{i=1}^{N} p_i(x,y) \qquad (3)$$

and locate the epicenter in the point corresponding to the maximum value of p(x,y) which can be shown to represent a binormal distribution for $N \geq 2$. In addition to the location of the maximum point (point of maximum likelihood), we can analytically find the axes and orientation of the confidence ellipses of the resulting distribution.

H. Gjøystdal

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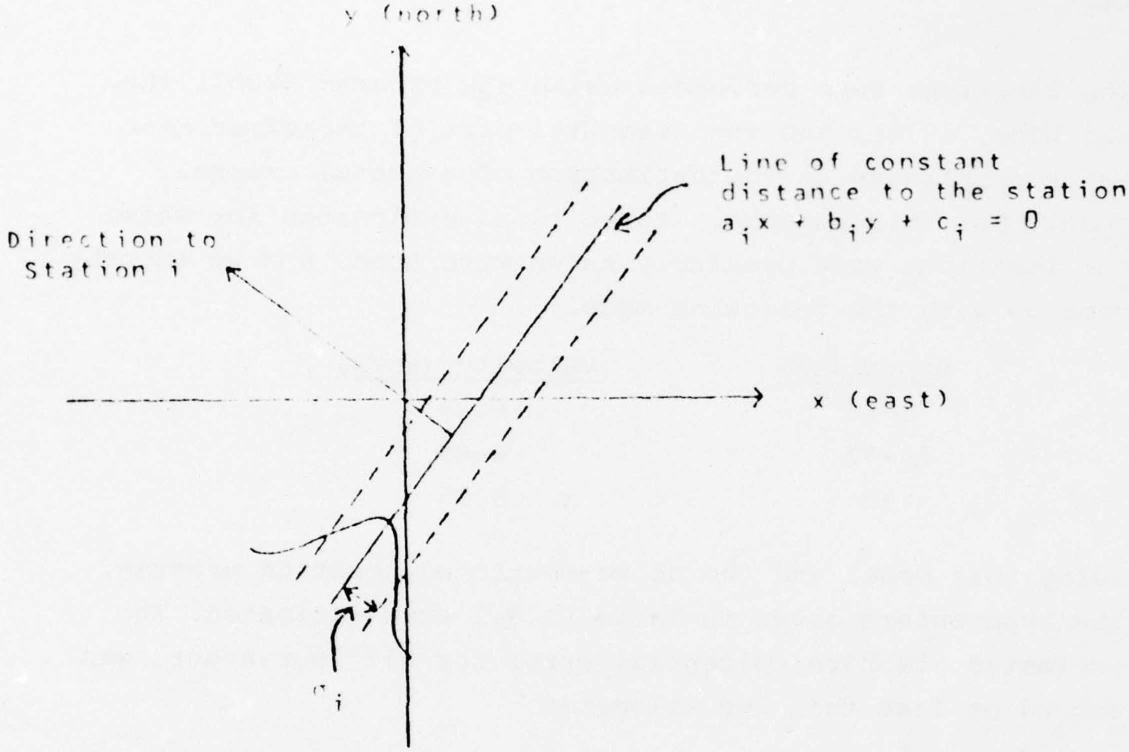

Fig. VI.7.1 Error distribution of the 'distance line' from each station, calculated from the P-S times.

VI.8 Precisely Located Earthquakes in the Vicinity of NORSAR

Even though local earthquakes in the siting area of NORSAR are quite rare (Husebye et al, 1978), there occurred between 1970 and 1978 four such events that could be subjected to a detailed hypocentral investigation using the NORSAR recordings.

The locations were performed using the program HYPO71 (Lee and Lahr, 1975), and the essential part of the experiment was concentrated on the estimation of a useful crustal model. For this purpose, three local explosions for which the locations were precisely known were used, and we thereby came up with the following model:

Depth (km)	Velocity (km/s)
0-16	6.25
16-32	6.65
>32	8.15

Using this model and the above-mentioned location program, the hypocenters given in Table VI.8.1 were estimated. The estimated standard epicentral error for all four events was around or less than one kilometer.

Table VI.8.1

Estimated hypocentral coordinates for four earthquakes in the NORSAR area.

No.	Date	Time of Day	Lat (N)	Long (E)	Depth (km)
1	71.07.19	00.59.11.5	60°43.1'	10°43.6'	31
2	73.10.01	16.44.14.3	59°55.1'	11°25.4'	6
3	73.11.23	06.49.36.9	60°33.2'	11°28.2'	23
4	77.12.11	21.46.12.1	60°56.7'	10°53.1'	22

In order to investigate the resolution of the depth estimation, an experiment was performed in which the hypocenter was constrained at given depths between 0 and 40 km and the associated RMS error in seconds was computed. The results are shown in Fig. VI.8.1, where it is seen that the resolution is fairly good for all of the events.

The hypocentral solutions presented here are the most accurate ones so far published for earthquakes in Fennoscandia, and this applies in particular to the focal depths. It is therefore interesting to note that our results are consistent with those of Husebye et al (1978), who found from macroseismic data that most of the depths should be in the range 15-30 km.

H. Bungum

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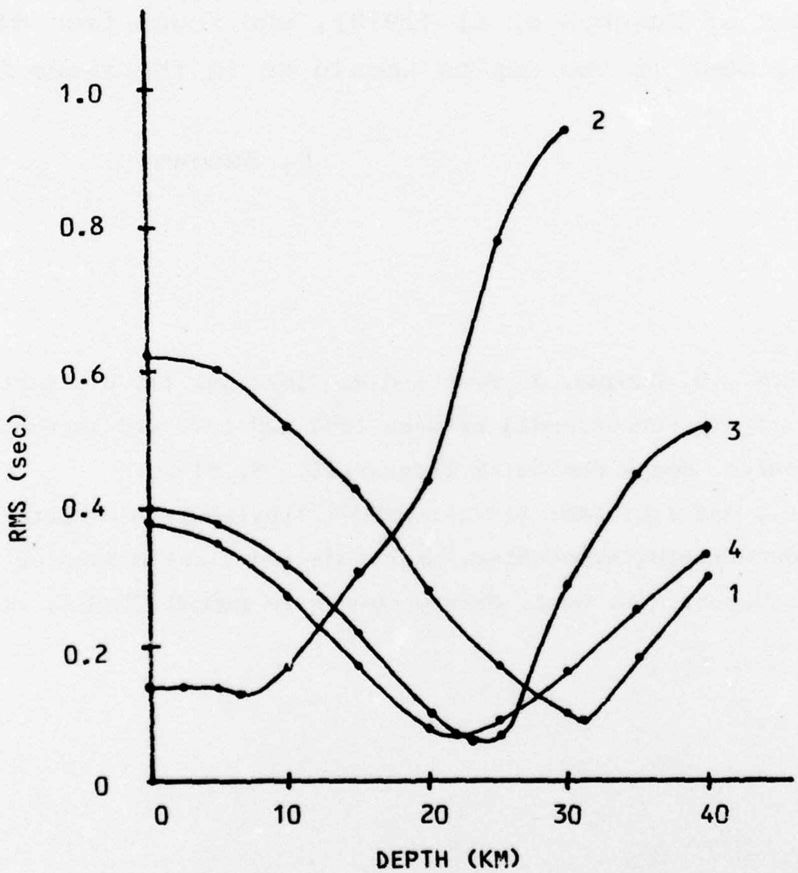

Fig. VI.8.1

VI.9 Macroseismic Data Collection Using Newspaper Ads

On the basis of the promising results obtained in developing a method and a procedure for automatic processing of macroseismic questionnaires (Husebye et al, 1976), it was found desirable to change the format of the questionnaires so that they would be more directly suited for analysis. Also, with the present great interest shown by the news media in connection with local earthquakes, it was also tempting to take advantage of this professionally. Consequently, a project was initiated (in cooperation with University of Bergen) in which macroseismic questionnaires now are regularly published as newspaper ads, in a format shown in Fig. VI.9.1. The questions are answered by crossing for 'yes', 'no' or 'don't know'. So far, the new format and the new data collection procedure have been tested on the four earthquakes listed in Table VI.9.1, where it is seen that 230 replies were received for one of the events. While the data still are under analysis for all of the events, Fig. VI.9.2 shows the geographical distribution of the answers, which of course in this case is convolved with the distribution of the newspapers.

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References

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Table VI.9.1

List of earthquakes for which questionnaires have been published as newspaper ads.

No.	Date	Place (in Norway)	No. of Replies
1	11 Dec 1977	Brumunddal	108
2	9 Jan 1978	Stord	69
3	20 Mar 1978	Møre	230
4	29 Apr 1978	Grong	?

Jordskjelvet ved Møre den 20. mars kl. 04.58

Som et ledd i et forskningsprosjekt i samarbeid mellom det seismologiske observatoriet NORSAR på Kjeller og Jordskjelvstasjonen i Bergen ber disse institusjonene her om publikums hjelp til å kartlegge virkningene av jordskjelvet den 20. mars kl. 04.58. - Spørsmålene retter seg til beboerne av det enkelte hus/leilighet, og dersom spørsmålet ikke er aktuelt, krysses det av i kolonnen for «vet ikke». En er også interessert i svar fra personer som bor i rimelig nærhet av skjelvet og som ikke har merket noe.

Navn og adresse (bare hvis ønskes): ....

Nøyaktig stedsangivelse (viktig!): ....

Jordbunnstype: Sand ☐ Leire ☐ Løsmasser (ikke spesifisert) ☐ Kompakt grunn (sand, stein) ☐ Fjell ☐

Bygningstype: Tre ☐ Mur/lett betong ☐ Betong ☐

Ja Nei Vet ikke

☐ ☐ ☐ Ble skjelvet merket? (Hvis «Nei» eller «Vet ikke», kan øvrige spørsmål ignoreres).
☐ ☐ ☐ Ble skjelvet merket av de fleste i huset/leiligheten?
☐ ☐ ☐ Ble skjelvet merket av alle i huset/leiligheten?
☐ ☐ ☐ Ble skjelvet merket utendors?
☐ ☐ ☐ Ble skjelvet merket av de fleste utendørs?
☐ ☐ ☐ Ble rystelsen merket som en svak skjelving?
☐ ☐ ☐ Ble vibrasjonene merket som en passerende lastebil/tog?
☐ ☐ ☐ Ble rystelsen merket som ved en sprengning?
☐ ☐ ☐ Hvis om natten, ble sovende personer vekket?
☐ ☐ ☐ Var det vanskelig å holde balansen mens skjelvet pågikk?
☐ ☐ ☐ Klirret vindusruter eller ovner?
☐ ☐ ☐ Svinget lamper eller andre hengende gjenstander?
☐ ☐ ☐ Knaket det i vegger eller gulv?
☐ ☐ ☐ Ristet møbler?
☐ ☐ ☐ Beveget bilder på veggen seg?
☐ ☐ ☐ Stoppet pendelur?
☐ ☐ ☐ Ble små og lette gjenstander forflyttet (eller veltet)?
☐ ☐ ☐ Var det noen dører eller vinduer som åpnet seg eller slo igjen?
☐ ☐ ☐ Falt bøker ned fra hyllene?
☐ ☐ ☐ Ble større møbler forflyttet?
☐ ☐ ☐ Ble glass eller porselen knust?
☐ ☐ ☐ Ble møbler beskadiget?
☐ ☐ ☐ Ble små skader på hus eller murvegger observert?
☐ ☐ ☐ Ble det observert større skader på hus eller murvegger?
☐ ☐ ☐ Ble det observert skader på veier (sprekker i veibanen)?
☐ ☐ ☐ Ble det observert skader på vannledninger?

Vennligst kryss av, klipp ut og returner skjemaet til:

JORDSKJELVSTASJONEN, Allegt. 41, 5014 Bergen U.
eller: NTNF/NORSAR, Postboks 51, 2007 Kjeller.

Fig. VI.9.1 An example of an earthquake questionnaire as a newspaper ad, 20 March 1978.

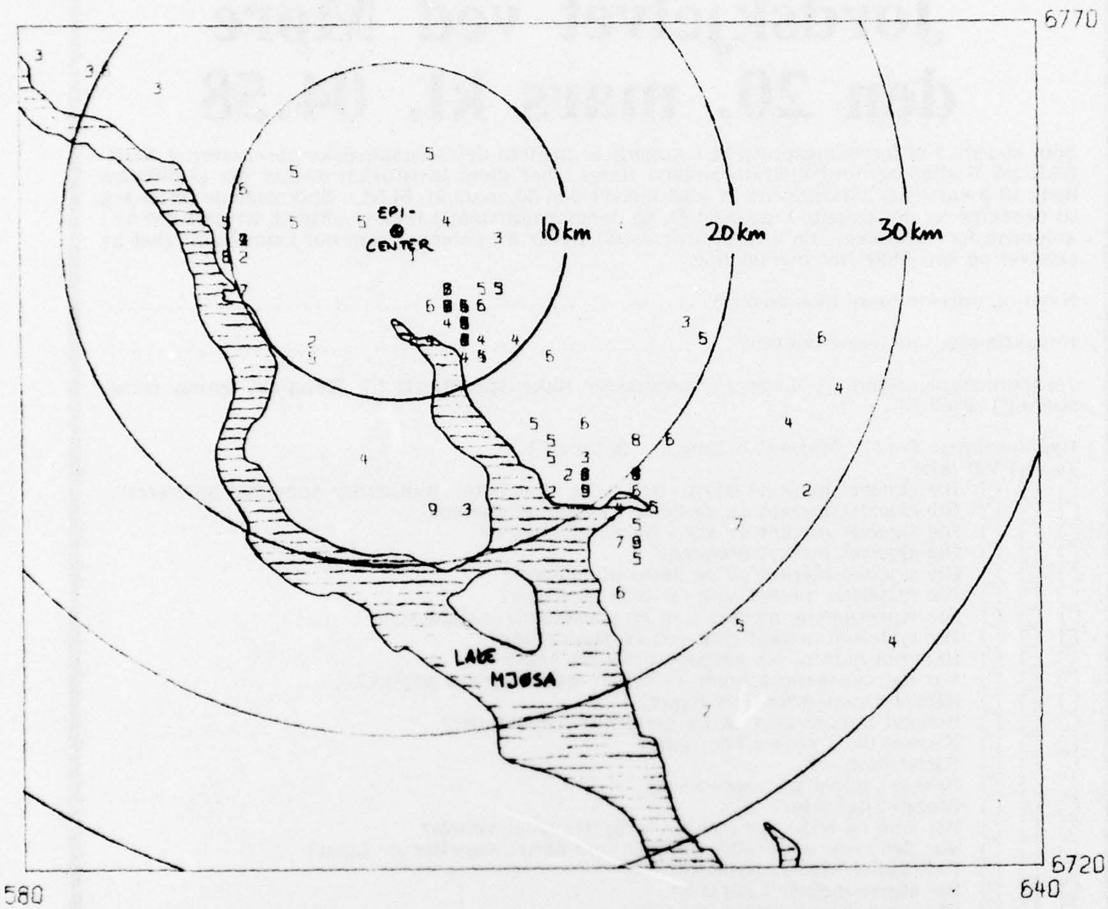

Fig. VI.9.2 Locations of returned questionnaires for Event No. 1 in Table VI.9.1. The numbers indicate number of 'yes'-answers. This earthquake is also discussed in Section VI.8.

VI.10 Seismicity of East Africa

As part of a seismic risk analysis for a planned dam project in Stiegler's Gorge, Tanzania, NTNF/NORSAR has conducted an extensive study of the seismicity and tectonics of Eastern Africa. Seismologically, this is a very interesting region as it encompasses the East African Rift System, and it has consequently been the subject of numerous studies in the past (see, e.g., Maasha and Molnar, 1972). Fig. VI.10.1 shows the distribution of seismicity in the area covered by the present investigation, based on a catalogue of 4069 known earthquakes compiled by NTNF/NORSAR. The high seismic activity along the rift zones may be clearly identified; however, it is of interest to note that the seismic activity shows wide distribution also outside this main system. In this respect, the seismicity of East Africa shows clear similarities to what has been observed in other intraplate areas such as Northern Europe, Russia and Northeast America.

Special attention was given in the NTNF/NORSAR study to comparing the earthquake magnitudes reported by various agencies to those calculated from NORSAR recordings. Fig. VI.10.2 shows a plot of NORSAR versus PDE (Preliminary Determination of Epicenters, U.S. Geological Survey) reported magnitudes. Although the data base is limited due to the short time period covered (6 years), it is evident that, relatively speaking, PDE shows a systematic positive magnitude bias, which is most pronounced for NORSAR magnitudes of about 4.0. We attribute this to the network magnitude bias problem discussed, e.g., by Ringdal (1976). Similar results were found when comparing NORSAR m_b to those of other agencies such as the International Seismological Centre (ISC). This is consistent with observations from other regions, and it appears that earthquakes with a PDE or ISC reported m_b of 5.0 or above in many cases will have a considerable positive bias, sometimes as much as a full magnitude unit relative to a hypothetical 'true' magnitude.

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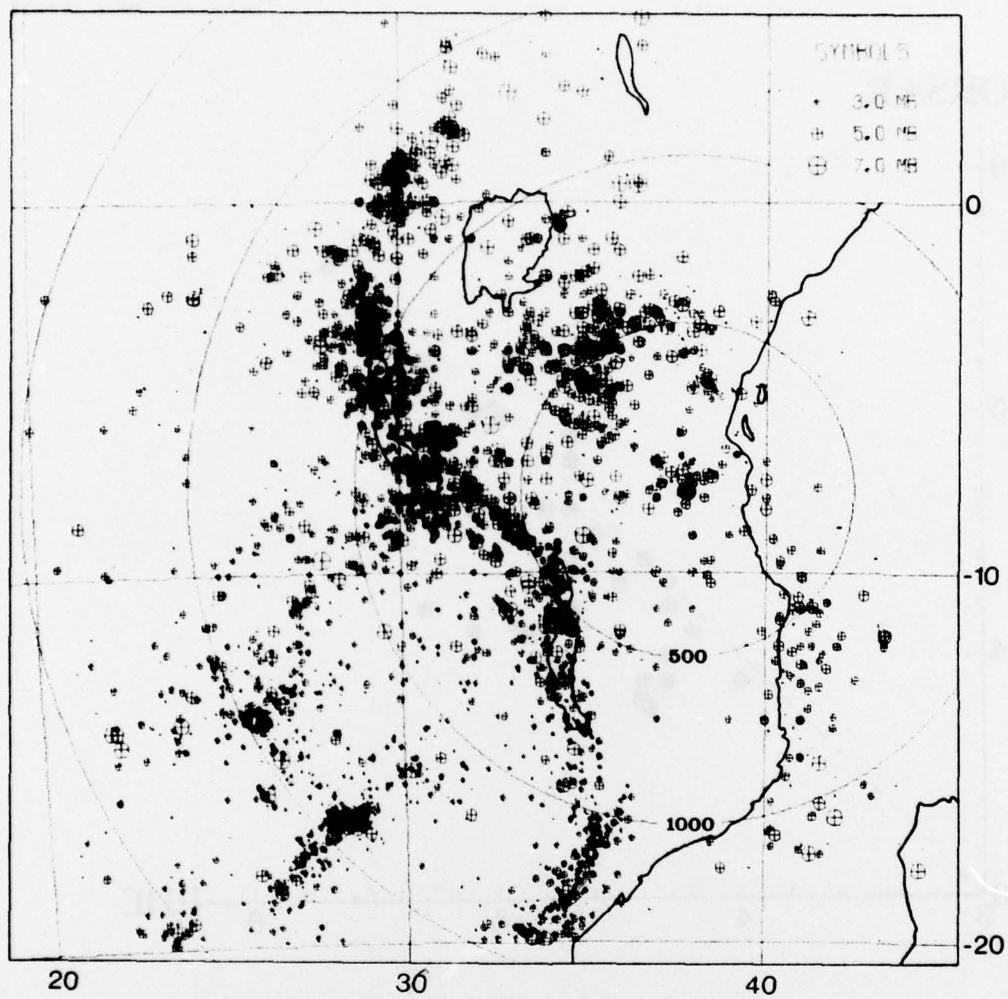

Fig. VI.10.1 Locations of all 4069 events in the NTNF/NORSAR earthquake catalogue for Eastern Africa.

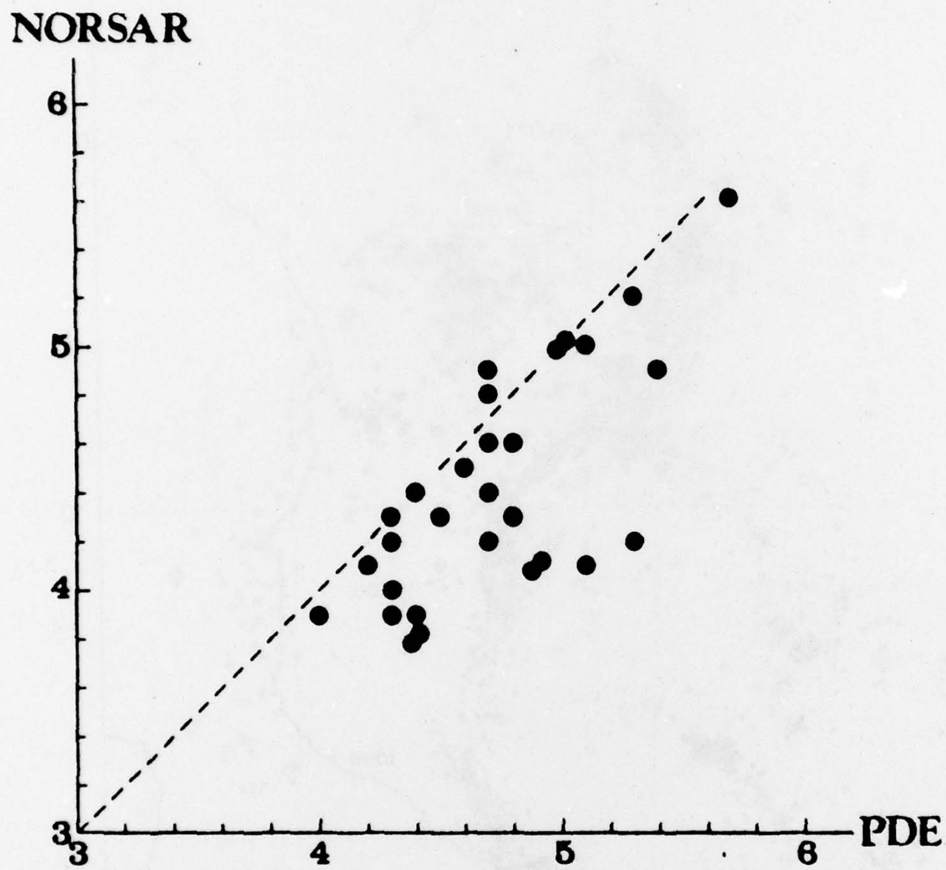

Fig. VI.10.2 Comparison between magnitudes of Eastern Africa earthquakes as reported by PDE and NORSAR.

VI.11 Lithospheric Thicknesses in the General NORSAR Siting Area

An integral concept in modern plate tectonic hypothesis is the structural units lithosphere and asthenosphere, and as such also widely used in seismological contexts. The basic differences betwen these two uppermost layers of the earth are slightly lower velocity but much lower attenuation and viscosity in the asthenosphere than in the lithosphere. The a-factor is of particular importance in near-field (range 0-30^{o}) seismological studies, as event detectability would be inversely proporitional to the Q-factor. Furthermore, there are considerable regional lithosphere differences; for example, heat flow and surface wave studies indicate that the lithosphere in shield areas like Fennoscandia is relatively thick as compared to oceanic areas (Pollack and Chapman, 1977; Lee and Solomon, 1975) 1974). In the latter case, the lithosphere-asthenosphere transition is generally marked with a pronounced velocity reversal. The combination of thick lithosphere and high Q-values clearly implies good seismic event detectability in the near-field distance range as demonstrated by Khalturin et al (1977) and some preliminary results on related problems have been published by Husebye et al (1977). Anyway, the topic of this section is to describe an experiment aimed at estimating lithospheric thickness by observations and analysis of so-called S-to-P converted waves associated with a discontinuity tentatively interpreted as the lithosphere/asthenosphere boundary (see Fig. VI.11.1). This research started in 1976 when Dr. I.S. Sacks of Carnegie Institute, Washington, D.C., visited NORSAR, and has now been completed (see Sacks et al, 1978).

Arrivals interpreted as Sp with a conversion beneath the Baltic Shield (Umeå area, NE Sweden) were found at NORSAR for 5 events in the epicentral range 70-82° with back azimuths of 37-57°. In the following we discuss the analysis of one of these events in some detail with emphasis on particle motion processing of the records (see Husebye et al, 1975). Discontinuities in the particle motion can be used to determine the initial onset of phases whose long period character makes this difficult to establish precisely from the time domain record. Fig. VI.11.2 shows the vertical radial and transverse components and the particle motion for the minute preceding direct S. Before Sp (Fig. VI.11.2 (1)) the particle motion is not in the earthquake-station great circle path. After the Sp onset the particle motion is along azimuth (Fig. VI.11.2 (3 upper) and in the vertical plane the particle motion (Fig. VI.11.2 (3 lower)) is a tight ellipse. The onset of Sp can be determined by tracing the motion backwards in time to the point where the particle motion breaks from the smooth elliptical motion (Fig. VI.11.2 (2 lower)). The motion associated with Sp persists until the shear arrival (Fig. VI.11.2 (4)), when the dominantly radial motion changes to transverse.

Using arrival times determined from the particle motion, the differential travel time for this event is found to be 29 $\pm$ 1 sec which implies a cnversion depth of 250 $\pm$ 15 km. Very similar results were obtained for the other 4 events.

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E.S. Husebye
J.A. Snoke (Virginia Polytechnical Institute & State University)

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Sacks, I.S., A. Snoke and E. S. Husebye (1978): Lithospheric thickness beneath the Baltic Shield. J. Geophys., in press.

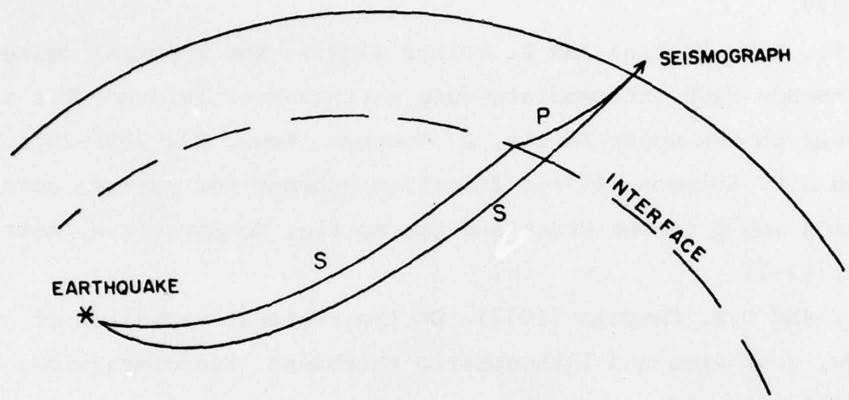

Fig. VI.11. 1 Ray paths of direct S and Sp.

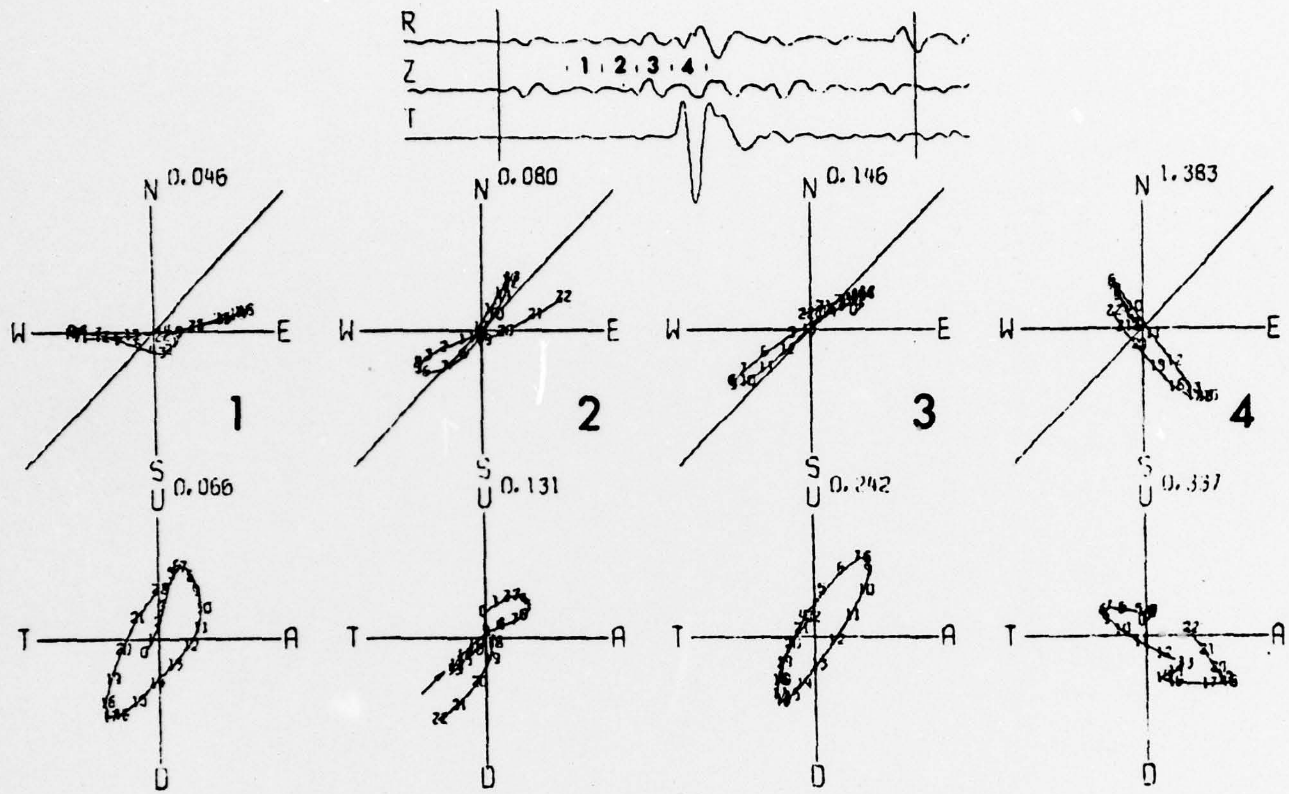

Fig. VI.11.2 Seismograms and particle motion for a single 3-component seismometer set for a deep-focus earthquake near Bonin Isl. 31 Jan 1973. The upper particle motions are in plan view, where the radial direction is indicated. The lower part of the figure shows particle motions in cross sections taken along the radial of the time windows marked in the (upper) seismograms. The particle motion numbers give time in seconds within each window, while the larger numbers to the right indicate relative amplitudes.